Remote Sensing Risk Assessment of Valdez Glacier Lake

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Research Question

Can remote sensing techniques be used to determine the probability of an outburst from the Valdez Glacier Lake, and to detect downstream areas affected by a possible glacier lake outburst flood?

Objectives

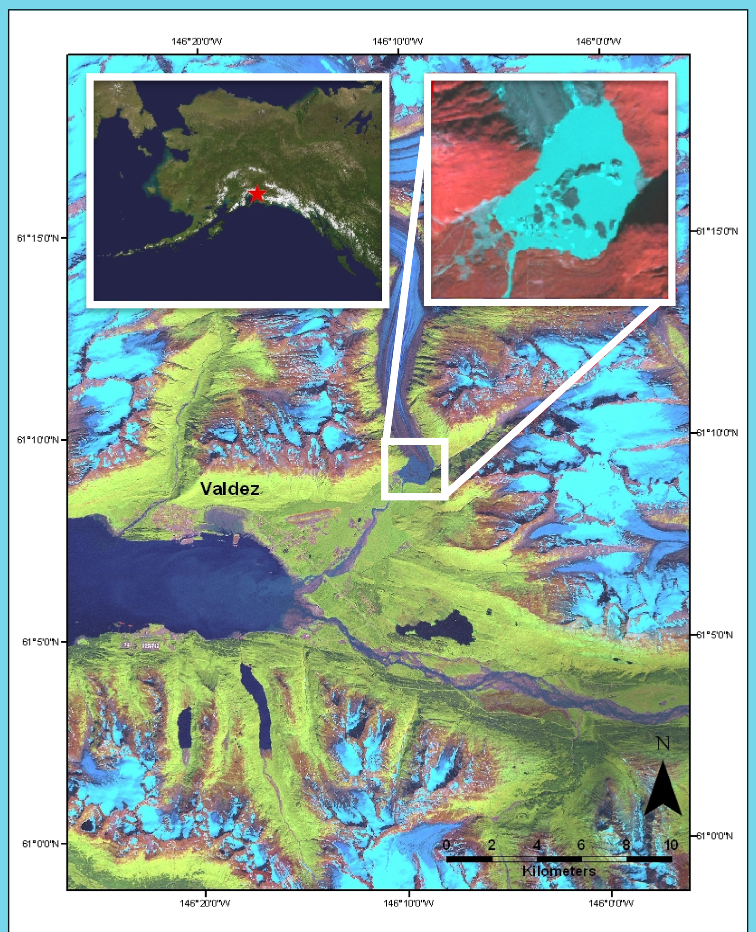
1. Determine the change in lake area over time.
2. Determine the probability of outburst.
3. Determine lake volume peak discharge and map downstream areas affected by a possible glacier lake outburst flood.

Introduction

One of the most observable impacts of a warming climate of is the retreat of alpine glaciers worldwide. As glaciers retreat, pro-glacial lakes are often formed between the retreating ice and an impounding terminal moraine. Many of these newly formed glacier lakes are unstable and can experience outburst floods that are threatening to downstream communities and infrastructure (Bajracharya et al. 2008). A moraine dam may fail due to internal weakening of the dam itself, due to ablation of ice within the moraine (Richardson & Reynolds 2000), or it may fail due to some external trigger such as displacement waves, earthquakes, upstream floods from ice dammed or supra glacier lakes (Shrestha 2008), or heavy rainfalls events (Narama et al. 2009). A single glacial outburst flood event can cause devastation costing hundred million dollars as well as loss of human lives. A risk assessment can provide important information for decision makers in order to carry out proper planning, mitigation and adaptation strategies (Shrestha et al. 2010, Bajracharya et al. 2007). This study is a first risk assessment of Valdez Glacier Lake, and an attempt to better understand the possible hazard to the community of Valdez, AK.

Study Area

Valdez Glacier Lake is a moraine-dammed lake located at the terminus of the Valdez Glacier. The lake is located at 61° 09'10" N and 146° 09' 25" W, at an elevation of 69 meters above sea level, 10 km north east from the city of Valdez. The average annual total precipitation of Valdez is 1,712.2 mm, with extreme events of over 100 mm precipitation per day possible (The Alaska Climate Research Climate Center). The geology around Valdez is dominated by Sedimentary rocks such as litharenite sandstone and argillite. (Kochelek et al. 2011) The Valdez region is also in an earthquake prone area (Begét 2007).



Methods

The development of Valdez Glacier Lake over time was determined by making comparisons between a 1950 aerial photograph, a 1978 aerial photograph, a 1995 LANDSAT 5 image, and a 2010 SPOT 5 image. Changes in lake surface area were measured by digitizing lake shorelines and position of the calving terminus in Arc GIS. Outburst probability was estimated using an empirically derived equation based on the 4 most statistically important factors; moraine dam height-to- width ratio, ice content of moraine, lake area, and type of geology (McKillop & Clague 2007). Moraine destabilization and ice-melt collapse was detected by comparing aerial photos from 1978 and 2006.

Outburst Probability Equation

$P(Y = 1) = (1+EXP(-(a\ constant+(B_1\ constant)*(M\_hw\_ratio)+(B_j\ constant)*(Ice\_core_j)+(B_2\ constant)*(lake\ area\ ha)+(B_k\ constant)*(Geology_k))))^{-1}$

a constant = -7.1074

B_1 constant = 9.4581

B_j constant = -1.2321 if ice-cored

1.2321 if not ice-cored

B_2 constant = 0.0159

B_k constant = 1.5764 (Granitic)

3.1461 (Volcanic)

3.7742 (Sedimentary)

-8.4968 (Metamorphic)

M_hw_ratio = morine height-to-width ratio

Ice_core_j = 1 if moraine is ice-cored, 0 if the moraine is ice-free

Lake area ha = lake area in hectares

$Geology_k$ = 1 if the main rock type forming the moraine dam is k and 0 otherwise.

(McKillop & Clague 2007)

The volume of Valdez Lake was determined by measuring the lake surface area in 2010 using Arc GIS, and applying empirical relationships between lake area and average lake depth (Huggel et al 2002). Lake volume was then used to calculate peak discharge with following equation for moraine dams (Costa & Schuster 1988).

$$Q=0.00013(PE)^{0.60} \qquad r^2 = 0.78$$

Where potential energy (PE) = dam height (meters), lake volume (cubic meters) and the specific weight of water (9,800 newtons/cubic meter).

The Costa and Schuster (1988) model provided empirical values for different types of natural dams. In addition to the moraine dam type, I also chose a flatter and wider 'landslide dam' model that most approximated the Valdez moraine dam, and a 'worst case scenario' potential peak discharge developed from historic failures of all dam types.

Mapping of downstream impacts is being assessed in the GIS based software HAZUS MH, using a DTM (LiDAR 2006) and estimated peak discharge rates. This work is still in progress, but is expected to produce a downstream risk map.

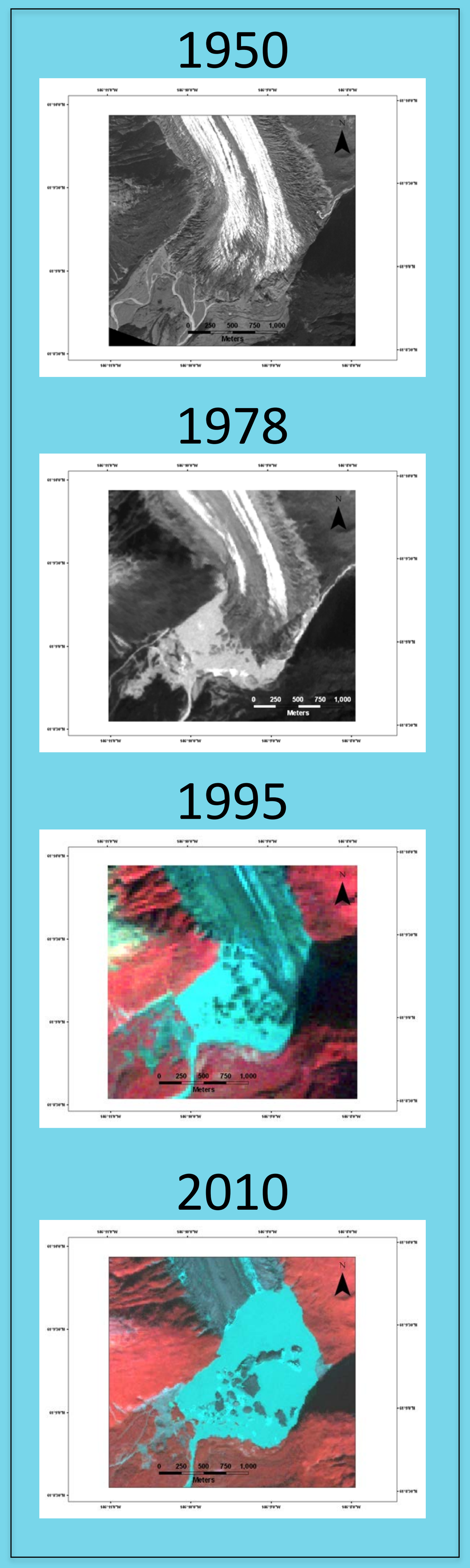


Figure 1: Change in glacier extent and lake area from aerial photos and satellite images between 1950-2010

Results

Glacier retreat and lake change

Valdez Glacier has retreated almost 1.9 km during the last 60 years, resulting in the formation of Valdez Glacier Lake. This lake was not present in 1950, but has grown to an area of 1.8105 km² as of 2010.

1950-2010

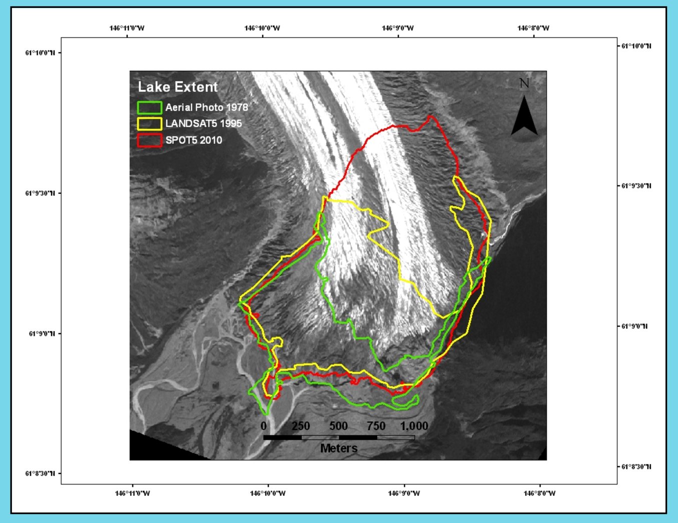


Figure 2: Composite map showing ice retreat and lake change 1950-2010

Outburst Probability

Thermokarst collapse features and the formation of kettle lakes observed in the 2006 LiDAR DTM (Figure 3) and aerial photos indicate that the moraine is partly ice-cored, that the ice is melting, and that the moraine surface and subsurface is unstable (Figure 4). An outburst flood probability model developed by Mckillop & Clague (2007) returns a percent probability of 16.9% for a frozen ice-cored moriane, which is considered "medium probability (12-18%)" of outburst. For a half ice- cored (or melting) moraine, the probability rose to 41.1 %, and to 70.5 % for ice-free moraine. The latter two are both considered to have a "very high probability" risk of outburst flood.

It is reasonable to expect that the outburst probability risk will increase in the future with continuted ice-core ablation de-stabilization of the moraine. Active collapse and kettle lake formation on the surface of the moraine were observed in aerial photos between 1978 and 2006. Further subsurface melt and collapse of the moraine could possibly lead to the formation of a new lake outlet to the left of the current one. Older stream channels indicate a complex drainage system, possibly formed by earlier outburst floods or lake outlets. These older channels could capture flow in a outburst flood.

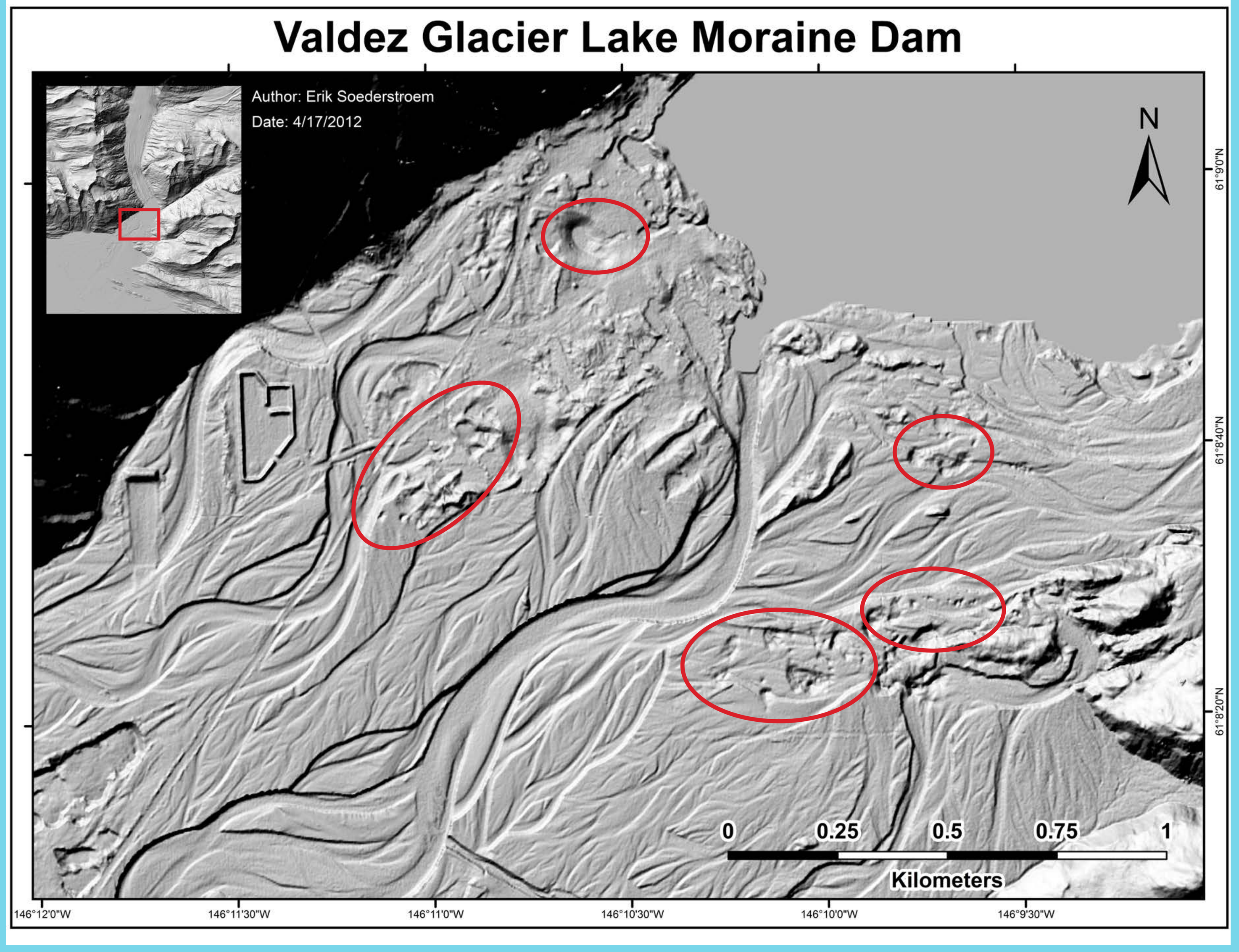


Figure 3: Red circles indicate areas of thermokarst collapse features and the formation of kettle lakes. Hillshade map generated from the 2006 LiDAR DTM.

Areas of Active Moraine Surface Failure / Ice Melt Occurring Between 1978 and 2006

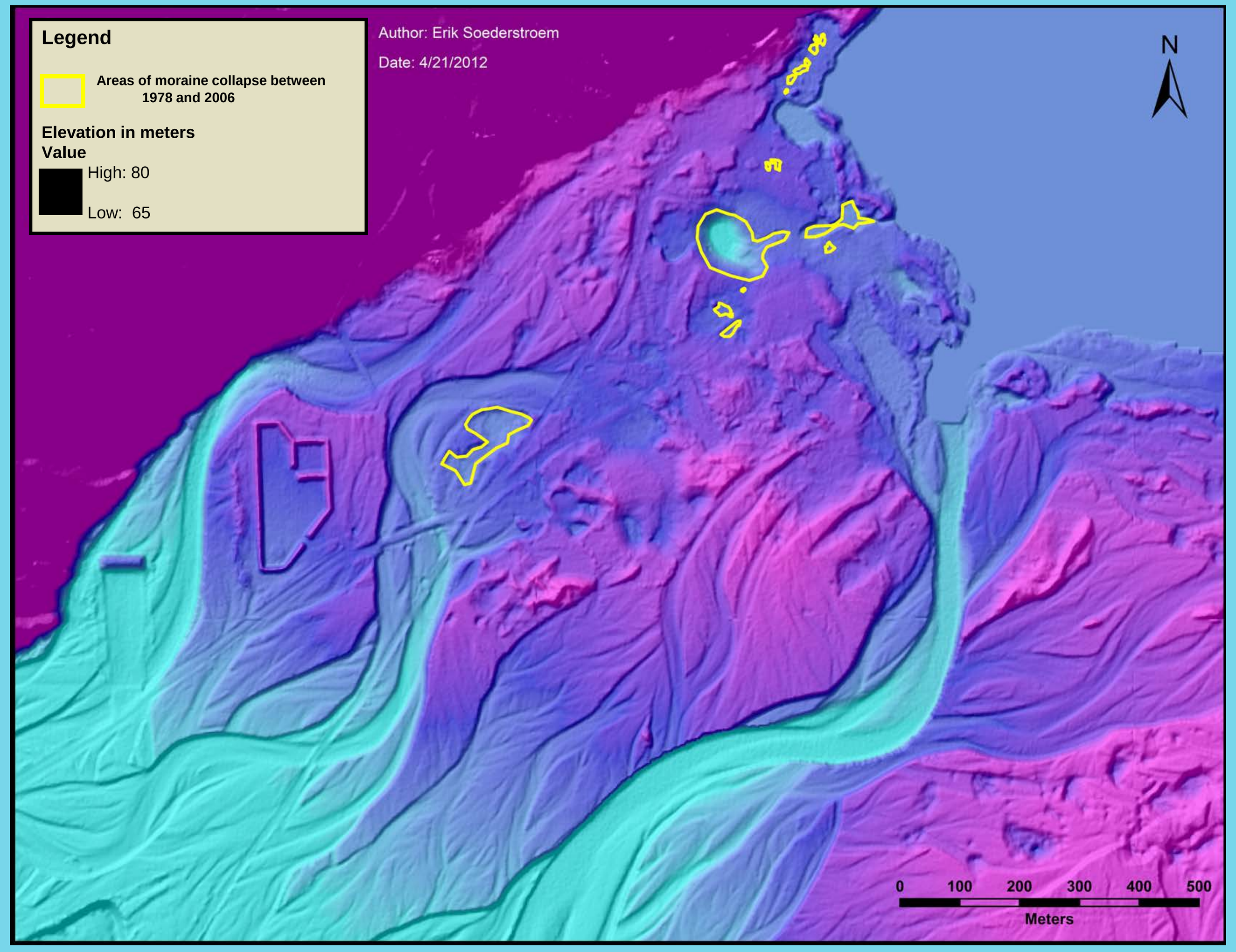


Figure 4: Areas of active moraine surface failure occurring between 1978 and 2006 indicated in yellow polygons, on top of a hillshade map with elevation coloring. Where areas with elevation values of 80 meters and greater are displayed in dark pink and areas of 65 meters and below are displayed in teal. Values in between are represented along the color scale. Note: lake surface elevation is 69 meters.

Peak discharge and potential flood path

The volume for Valdez Glacier Lake was estimated to 80,003,310 m³. Peak discharge volumes for each of the modeled dams was estimated to be:

- moraine dam - 6654 m³/s
- landslide dam - 2928 m³/s
- 'worst case' - 15694 m³/s

Figure 4 elevation model shows collapse areas, potential new outlet formation, and potential flood pathways where surface elevation is at or below lake level (light teal color is 65 or below). Efforts to model potential downstream flood impacts are underway using GIS based HAZUS MH.

Recent Surface Collapse on Moraine

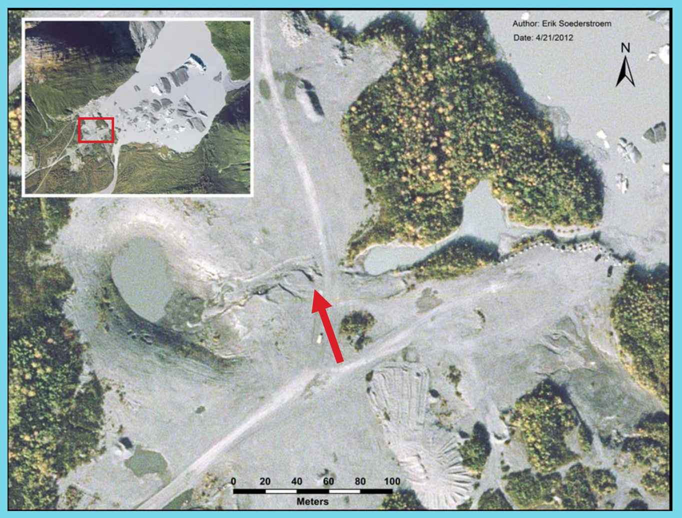


Figure 5: Area of active subsurface ice melt and moraine collapse. Formation of kettle lake has occurred between 1978 and 2006. Arrow points to headward erosion and the potential formation of a new lake outlet.

Conclusions

- Valdez Glacier has retreated almost 1.9 km during the last 60 years.
- Valdez Glacier Lake has grown to an area of 1.8105 km² as of 2010.
- Ice-melt collapse features and incipient kettle lakes indicate that the moraine is partly ice-cored and the ice is melting.
- Several areas of moraine dam subsurface ice melt and collapse were observed to have occurred between 1978 and 2006.
- Estimated outburst probability: 16.9 % ice cored moraine, 41.1 % for half ice-cored moraine, and 70.5 % ice free moraine.
- The volume for Valdez Glacier Lake was estimated to be ~80,003,310 m³
- Potential outburst flood discharge rates are estimated for moraine dam, landslide dam and 'worst case' discharge values at 6654 m³/s, 2928 m³/s, and 15694 m³/s respectively. Former channels may provide new pathways for outburst flood waters.

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References

Alaska Climate Research Center., 2012. *Alaska Climate Data, Precipitation.*
Bajracharya, B., Shrestha, A.B. & Rajbhandari, L., 2007. Glacial Lake Outburst Floods in the Sagarmatha Region. *Mountain Research and Development*, 27(4), pp.336-344.
Bajracharya, S.R., Mool, P.K. & Shrestha, B.R., 2008. Global Climate Change and Melting of Himalayan Glaciers Abstract : *Sciences-New York*, pp.28-46.
Begét, J., 2007. *Earthquake , Landslide and Tsunami Hazards in the Port Valdez area , Alaska : Consultation to the Prince William Sound Regional Citizen's Advisory Council*.
Costa, J.E. & Schuster, R.L., 1988. The formation and failure of natural dams.
Kochelek, E. J., Amato, J. M., Pavlis, T. L., & Clift, P. D. 2011. Flysch deposition and preservation of coherent bedding in an accretionary complex : Detrital zircon ages from the Upper Cretaceous Valdez Group , Chugach terrane , Alaska. *Lithosphere*, 3(4), pp.265-274.
McKillop, R.J. & Clague, J.J., 2007. Statistical, remote sensing-based approach for estimating the probability of catastrophic drainage from moraine-dammed lakes in southwestern British Columbia. *Global and Planetary Change*, 56(1-2), pp.153-171.
Narama, C., Severskiy, I. & Yegorov, A., 2009. Current State of Glacier Changes, Glacial Lakes, and Outburst Floods in the Ile Ala-Tau and Kungöy Ala-Too Ranges, Northern Tien Shan Mountains. *Geographical Studies*, 84, pp.22-32.
Richardson, S.D. & Reynolds, J.M., 2000. Degradation of ice-cored moraine dams : implications for hazard development. *IAHS*, (264), pp.187-197.
Shrestha, A.B., Eriksson, M., Mool, P., Ghimire, P., Mishra, B., & Khanal, N. R., 2010. Glacial lake outburst flood risk assessment of Sun Koshi basin, Nepal. *Geomatics, Natural Hazards and Risk*, 1(2), pp.157-169.
Shrestha, A.B., 2008. *Resource Manual on Flash Flood Risk Management*.